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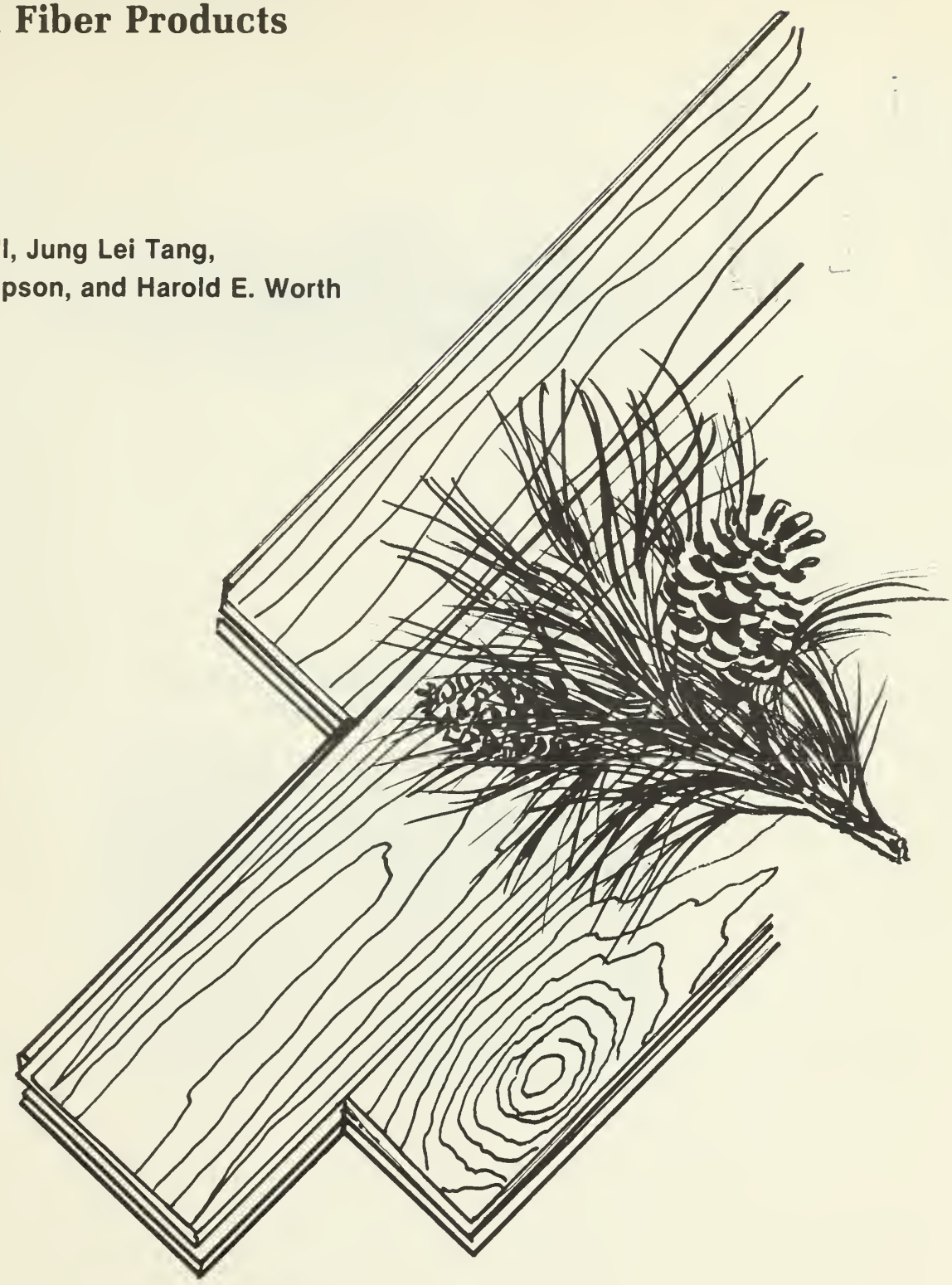
Suitability of Beetle-Killed Pine in Colorado's Front Range for Wood and Fiber Products

Harry E. Troxell, Jung Lei Tang,
George R. Sampson, and Harold E. Worth



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Abstract

Front Range beetle-killed ponderosa pine wood is suitable for most traditional uses of the species. Differences are: the beetle-killed timber is drier, usually blue-stained, and may contain wood borers and decay. Mechanical properties may be affected.

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Management Implications

A mountain pine beetle outbreak in Colorado's Front Range ponderosa pine was identified in 1976 as one of the most urgent forest management problems in the Rocky Mountain region. At the height of the outbreak, an estimated 27.3 million cubic feet of timber were killed each year in the Front Range.[2] Annual losses from mountain pine beetle are now declining, but substantial volumes of dead timber remain in some areas, and new beetle outbreaks are likely to occur in future years (Sartwell and Stevens 1975). The beetle-killed timber depreciates esthetics and is also a serious fire hazard. Removal of beetle-killed timber is very expensive unless part of the cost can be defrayed by selling the timber for conversion into industrial products or firewood. Consequently, the suitability of beetle-killed ponderosa pine for various uses will remain a major utilization problem for this region.

In addition, an effective program to control future beetle epidemics requires management of forest vegetation to create healthier growing conditions in timber stands. Vigorous, growing trees are less susceptible to insect attacks. For the control program to be both economically feasible and to meet national conservation objectives, it will be necessary to increase utilization of wood and fiber from the threatened living trees, recently killed trees, old standing dead trees and some of the non-threatened living trees.

Results of this study suggest that some properties of wood from standing beetle-killed trees are probably not affected enough to be of further concern, while others warrant additional study. In general, utilization characteristices of beetle-killed wood vary with the length of time trees are dead before being harvested. The longer dead trees are left in the woods, the higher the risk of excessive deterioration. About 5 years appears to be the maximum length of time dead trees will remain in utilizable condition for wood products. But utilization of this Front Range pine does not depend solely on the technical characteristics of the raw material or on product requirements. Harvesting, transportation, and processing costs are critical factors, as are the product values that can be realized in the market place. Comparisons of costs and values of products made from dead and live trees are an appropriate basis for assessing these economic factors. Such comparisons are explored in a companion study by Sampson, Betters, and Brenner (1980).

Introduction

Epidemic attacks on ponderosa pine forests of Colorado's Front Range by the mountain pine beetle (Dendroctonus ponderosae) forced forest owners in the 1970's to drastically alter plans for managing these forests. Massive numbers of beetle-killed trees left in the forest created an unacceptable scenic blight and fire hazard. Eventually, as the dead trees rot and fall down, they would also become an obstacle to regeneration and other management objectives. Further, because overcrowed stands are believed to invite heavy beetle infestations, managers consider it essential to thin out vulnerable living trees to reduce future threats and create better growing conditions. What to do with the beetle-killed and beetle-threatened trees was, and is, a major concern for forest managers and the general public alike.

The cost of removing and disposing of the dead and threatened timber was found to be higher than most owners could finance. The natural response was to seek ways to reduce this cost.

To help meet the need, this study examined beetle-killed trees, dead 5 years or less, their suitability for various products, and determined the properties that may affect or limit their use. The scope of the problem and the high cost of a definitive study of all characteristics dictated that this study be confined to an exploratory evaluation. Also, the stands and individual trees for which there was a record of their year of death were extremely limited. As a consequence, the size of the sample for which the several variable characteristics of trees could be measured was unavoidably small. Results, therefore, do not necessarily apply to other Front Range trees or forests even though reason suggests that similar characteristics might be found under like conditions. Results presented here are based on a more detailed report prepared by Tang and Troxell in 1977.[3] Related studies on the amounts and kinds of raw materials potentially available (Sampson, Betters, and Love 1980) and on the industrial capacity needed to utilize the wood (Sampson, Betters, and Brenner 1980) are reported elsewhere.

[2] *U. S. Department of Agriculture, Forest Service [1976]. Western forest insect problem area analysis. 6 p. U. S. Department of Agriculture, Forest Service, Rocky Mountain Region, Denver, Colo. [Unpublished report.]*

[3] *Tang, Jung Lei and Harry E. Troxell. 1977. Suitability of beetle-killed pine in Colorado's Front Range for wood and fiber products. 53 p. Colorado State University, Fort Collins, Colo. [Unpublished report.]*

Timber Characteristcs

Physical Stem Characteristics

Ponderosa pine timber includes a wide range of age classes and site conditions. The vigor of trees in ponderosa pine stands varies greatly. Beetle-killed trees usually are in scattered clusters, with individual trees varying in the length of time they have been dead. Two common types of damage found in standing dead ponderosa pine timber are broken tops and fire or lightning scars. Trees dead more than 2 years develop prominent checks in the wood. Such checks often appear in places where the wood is exposed as the bark loosens or falls off. These defects all tend to reduce the volume or grade yield of wood products made from dead timber.

The inner bark of beetle-killed trees is characterized by numerous main vertical bark beetle galleries, with secondary ones branching off laterally. Following bark beetle attack, the sapwood is further attacked by blue-staining fungi and ambrosia beetles. The extent of their presence in a tree is directly related to the length of the time the tree has been dead and greatly affects the suitability of the wood for lumber and other wood produce. Five years seems to be the maximum period of time standing trees can be salvaged; however, considerable deterioration is noted during and after the third year. Some usable fiber may remain in the tree for many years, particularly for fuel wood use.

Figure 1.—Selection of logs killed by the bark beetle illustrating the patterns on the end sections caused by blue-staining fungi.

Wood Properties

The suitability of beetle-killed ponderosa pine wood for products depends upon several wood properties, such as specific gravity or density, shrinkage, shock resistance, mechanical strength, and visual appearance. Other properties, such as pH value, wettability, and extractive characteristics also affect suitability for other wood products.

Wood appearance.—The appearance of wood from trees that have been beetle-killed is very distinctive and often esthetically pleasing. Wood in standing dead trees usually becomes heavily blue-stained soon after death. Blue-staining is caused principally by two species of fungi, *Ceratocystis montia* Rumb and Hune, and *Europhium clavigerum* Robinson and Davidson. Blue-staining fungi always accompany the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) and invariably invade beetle-killed trees. An unusual feature is the marked tendency of the stain to appear in radial streaks or wedge-shaped areas in sapwood. This is caused by the tendency of blue-staining fungi to associate with wood parenchyma tissue of the sapwood, which usually is found in the wood rays (fig. 1). Quite often associated with blue stain is a pink or purple stain caused by an as yet unidentified species of fungus. The purple or pink stain shows the same radial pattern as the blue-staining fungi on cross-sectional pieces of wood. Figure 2 shows some larger sized borer holes and numerous smaller pin holes, often associated with dark discoloration seen in ponderosa pine lumber sawed from the standing dead trees. These holes, created by ambrosia beetles which infest the sapwood after the bark beetle attack, are most numerous in the outer portion of sapwood. Figure 2 also shows the appearance of sap-stained pieces cut from the logs and made into dimension lumber. The unstained portions of the pieces are heartwood. The decorative character of blue-stained lumber can be further enhanced by special processing. During the latter years of the 1970's, large volumes of this wood were sold as interior wall paneling and trim for homes and commercial buildings.

Figure 2.—Sawed ponderosa pine dimension lumber from beetle-killed trees.

Specific gravity.—Specific gravity is useful as a means of predicting other properties, such as strength, shrinkage, hardness, and shock resistance; also for projecting the value of products, such as chips for pulp, firewood, and briquets. To obtain estimates of the

specific gravity of beetle-killed wood, full-length increment cores were collected from a sample of 21 standing dead and five live ponderosa pine trees in the Poudre Canyon area near Fort Collins, Colo. The sample was selected from trees 10-14 inches in d.b.h. that had died within the past 5 years. These same trees were used for testing moisture content, solubility, hydrogen-ion concentration, and wettability. All the increment core samples were taken at breast height. Specific gravities for the samples are listed below:

	Specific gravity, *(mean and standard error)*
Beetle-killed	
Sapwood	0.37 ± 0.05
Heartwood	0.46 ± 0.04
Live	
Sapwood	0.41 ± 0.02
Heartwood	0.46 ± 0.03

The specific gravity of heartwood of beetle-killed timber is the same as for live timber; however, the specific gravity of sapwood is slightly lower than for sapwood of the live timber. This difference has no practical signifiance with respect to most uses but is a probable indication that some minor loss of strength can be expected.

Moisture content.—Moisture content, which is important when considering weight, shrinkage, strength, and other technical properties of wood, was determined from the increment core samples used for specific gravity determinations. Moisture contents for sapwood and heartwood are as follows:

	%Moisture content *(mean and standard error)*
Beetle-killed	
Sapwood	40 ± 11
Heartwood	32 ± 5
Live	
Sapwood	150 ± 9
Heartwood	40 ± 7

A tree's sapwood loses a substantial amount of water after the tree dies. The moisture content in beetle-killed trees was highest at the base and decreased with increasing height in the tree (Barron 1971). The amount of drying depends on the length of time the trees have been dead. As the bark breaks up and falls off, the wood dries below the fiber saturation point, generating internal stresses that result in checks or splits. Figure 3 shows prominent checks extending deeply into the logs. Other wood properties mentioned before and product yields are adversely affected by this degree of checking. Lumber yields from deeply checked trees are reduced and lumber is narrower than if the trees were sound.

Figure 3.—Checks developed in beetle-killed logs.

Mechanical strength.—Strength properties of clear wood specimens for ponderosa pine are available from James (1968), Markwardt and Wilson (1935), and the USDA Forest Service, Forest Products Laboratory (1974).

The strength properties of beetle-killed ponderosa pine are difficult to relate to past studies of blue-stained wood (Chapman and Scheffer 1940, Findlay and Pettifor 1937, Findlay and Pettifor 1939). The situation is unique in that the ponderosa pine wood being studied has been killed and left unprotected in the woods, subject to blue stain and other wood-destroying fungi, for varying periods of time. In addition, weathering degradation of wood, particularly changes in moisture content, affects wood properties. Carey[4] tested small clear specimens of wood from beetle-killed Front Range ponderosa pine and reported that modulus of rupture, modulus of elasticity, compression parallel-to-grain, and shear parallel-to-grain properties all decreased about 10% and shock resistance (toughness) was reduced by almost 53%. The implications of Carey's study and the lack of other data suggest that a more comprehensive study is needed to provide information about wood strength from standing dead trees throughout the Front Range.

Shrinkage and permeability.—Wood changes dimensions when the moisture content falls below the fiber saturation point. Because of the orthotropic characteristic of wood, dimensional changes vary in the radial, tangential, and longitudinal directions. The differential in shrinkage between radial and tangential directions is an indication of woods's tendency to check and warp during drying. In general, greater differences in shrinkage result in greater severity of drying defects.

According to previous research (Nicholas 1973), blue-staining fungi obtain their nourishment primarily from materials stored in the parenchymatous cell

[4]*Carey, P. P. 1977. A review of blue stain research—where we are today. 14 p. Colorado State University, Fort Collins, Colo. [Unpublished paper.]*

cavities of the sapwood, and little damage occurs to the cell wall structure. However, the wood becomes more permeable, because of the attack of fungi. The fungi occupy the ray cells primarily, and the growth and development of the fungal hyphae extend through the pit structures of cell walls of tracheids in the sapwood (Scheffer and Lindgren 1940). The proliferation of the hyphae probably will affect the moisture content and permeability. However, the shrinkage behavior of the wood remains the same for a given change in moisture content. Only the percentage of absorption and the rate of penetration of liquids by the wood is increased (Lindgren and Scheffer 1939). This phenomenon helps to explain the fast penetration of chemicals into blue-stained wood and accounts for a three-fold increase in chemical uptake in preservative treatment by blue-stained wood compared to normal wood. Other wood-destroying organisms such as decay fungi and the larger wood borers, further hamper utilization of beetle-killed timber and are the principal factor limiting salvage to 5 years.

Solubility changes.—Chemical constituents of the wood cell wall change when exotoxins are present, as in blue-staining and other fungal attack. Measuring the solubility of wood constituents in a 1% sodium hydroxide solution is one way of testing this deterioration. In this study, a very limited test was made using wood from the sample trees. The procedures outlined by the American Society for Testing and Materials (1980b) were followed. One bolt was taken from a tree killed about 1973, one bolt from a tree which died in 1976, and one bolt from a live tree. The sapwood of these bolts was ground into a meal of 40 to 60 mesh. The means and standard errors for solubility in sodium hydroxide are 32.79% ± 0.08%, 14.99% ± 0.09%, and 11.52% ± 0.11% for the 1973, 1976, and live bolts, respectively.

The solubility tests based on the oven-dry weight of the wood before the test were made only on sapwood, which is free of the extractives normally stored in heartwood. The large increase in dissolved substance for the tree which died in 1973, therefore, presumably comes from the main cell wall constituents. Past studies utilizing the 1% sodium hydroxide solubility test have dealt with fungal degradation of wood by brown-rot fungi. Levi (1964) emphasized that brown-rots cause a rapid increase in solubility, largely because of an acidic condition of lignin derivatives, along with a rapid depolymerization of the carbohydrates, which takes place mainly in the amorphous regions of the microfibrils. Nicholas (1973) also reported a significant increase in solubility in a 1% sodium hydroxide for decayed wood attacked by brown-rot fungi. These results, although very limited, may imply that other fungi would also increase the solubility of beetle-killed material with time after death. Seifert (1964) stated that blue-stain fungi degraded wood substance and indicated 7% loss of cellulose and a 3-4% loss of hemicelluloses. This study, based on the blue-stain fungus (*Pullularia pullulans* (deBary) Berkout) and pine wood, was conducted in Germany. These results imply that some fraction of dissolved substances are formed from the attack of blue-stain fungi on wood, but other fungi are probably responsible for most of the solubility increase.

Hydrogen-ion concentration (pH).—Hydrogen-ion concentration (pH) was tested in cold water by soaking blue-stained wood meal samples (Stamm 1961) prepared from sapwood of sixteen beetle-killed trees from the Poudre Canyon sample. These were standing trees dead from 1 to 5 years. Control samples were prepared from sapwood of five normal live trees from the Poudre Canyon site and tested by the same method.

	pH Values, *(mean and standard error)*
Green wood	4.5 ± 0.06
Beetle-killed wood	4.3 ± 0.13

The minor difference in pH is not significant and should not be a barrier for most wood products, including those in which adhesives are involved.

Wettability.—Wettability is an important property that determines the affinity of wood for liquids. It affects the transfer and penetration of glue during application and ultimately the quality of glue performance in bonding. In this study, wettability of wood from beetle-killed trees dead 4 years was compared with that of wood from living trees (fig. 4). Three samples of each were taken from trees in Poudre Canyon. The capillarity of the meal was measured at different periods of time during the course of the tests until the heights in the capillary columns reached a constant level. This comparison shows a slightly higher degree

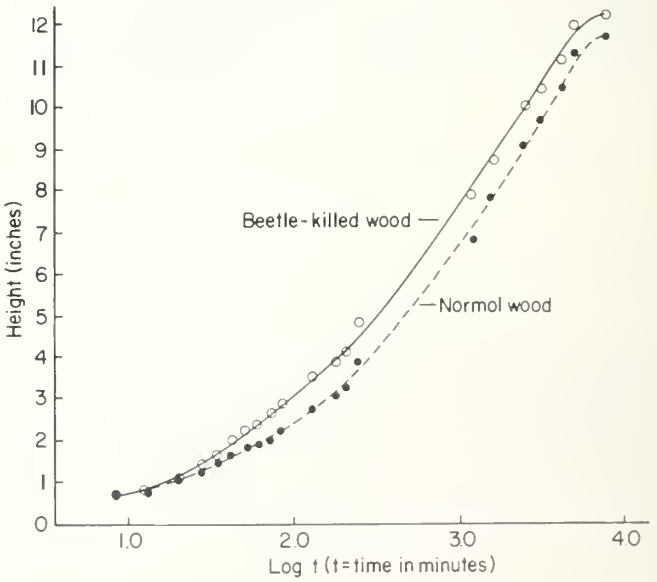

Figure 4.—Wettability of beetle-killed wood when compared with normal living wood (height means the height water rises in wood meal when packed uniformly in a 3/8-inch diameter vertical capillary tube when one open end is immersed in a reservoir of distilled water).

of wettability for wood from beetle-killed trees than for that from living trees. From this limited sample, it appears that wood from beetle-killed trees should produce glue bonds as good or better than normal wood.

Suitability of Beetle-Killed Wood for Various Products

An efficient and effective utilization program for Front Range beetle-killed and live ponderosa pine requires a diversified product mix because there is a wide variety of tree sizes and volumes per acre to be removed. New products not now being produced in the area must be considered if the available volume of live and dead timber is to be fully utilized.

Products Currently Produced

The major wood products now manufactured from ponderosa pine by the Front Range wood-using industry were investigated first. The information collected provides the main basis for predicting which wood products can be produced from beetle-killed, Front Range ponderosa pine.

Boards, dimension lumber, and timbers.—Figure 5 illustrates the various sizes and grades of boards, dimension lumber, and timbers typically produced from beetle-killed trees. A recent lumber recovery study found that lumber yield from some standing dead ponderosa pine trees approached that for live trees.[5] However, in general, a higher percentage of low-grade products will be obtained from dead trees. More narrow boards from the logs of dead trees should be expected. The general concept applicable to live trees that the higher grade lumber is cut from the clear outer sapwood layer seldom applies to beetle-killed trees, because stain, decay, and insect attack most frequently occur in that area. Blue-stained wood is generally allowed in dimension lumber, (e.g., studs) but decay is restricted.

The suitability of beetle-killed wood for studs depends on the degree of deterioration. Generally, the sound wood of beetle-killed ponderosa pine should perform satisfactorily. To confirm this, static bending tests were performed on a sample of 304, 2- by 4-inch studs obtained from 350 ponderosa pine trees (124 living and 226 beetle-killed) sampled from Roosevelt National Forest, Colo.[5] Beetle-killed trees were dead for varying periods of time up to 5 years.

The results show a trend for both normal and beetle-killed wood toward reduced strength and stiffness with progressively lower lumber grade (table 1). Within a grade, however, average values for fiber stress at proportional limit, modulus of rupture, and modulus of elasticity were not significantly different for normal and beetle-killed wood. Sources of variation such as differences in density, knots, grain deviations, etc. tended to overshadow any effects of wood deterioration that may have been associated with mountain pine beetle attack in this small sample.

[5]*Woodfin, Richard O. 1979. A utilization question—lumber recovery from dead ponderosa pine on Colorado Front Range? USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg. [Unpublished report.]*

Figure 5.—Various sawn products from beetle-killed logs—boards, dimension lumber, and timbers.

Paneling.—The presence of blue-stained sapwood of dead trees presents no special technological problems in the manufacture of paneling, and the natural discoloration in the wood makes it attractive to many users for decorative uses. In the Front Range region, blue-stained paneling from beetle-killed ponderosa pine wood is now being manufactured and marketed successfully (figure 6).

It is important to maintain high manufacturing standards in producing blue-stained paneling. Paneling for interior use should be delivered at a moisture content of about 5-8% to assure best performance in service. These levels may be achieved by air-drying in the Front Range during certain months, but kiln drying may be necessary or desirable to fumigate the lumber. Fungal activity is arrested when the moisture levels fall below 20%, but the eggs and larvae of insects such as roundheaded borers, termites, and carpenter ants that may be present in beetle-killed trees continue to function at lower moisture content. To assure an insect-free paneling product, manufacturing procedures must make certain any insects in the wood are killed. One way to do this is to heat the wood to temperatures higher than 180° F, as would be done in normal kiln drying.

Pallets.—Beetle-killed ponderosa pine seems to be suitable for pallets. Although one manufacturer had blue-stained wood pallets rejected by a customer who uses pallets in contact with foodstuffs, there is no evidence that blue-stain is harmful in this respect. Naturally occurring defects such as knots, checks, splits, shakes, diagonal or spiral grain, pitch pockets, and decay which affect strength of wood and consequently pallet performance, are no more of a factor in blue-stained than in normal wood. Blue-stained pieces, especially from dead timber, should be examined carefully and determined to be sound wood before they are selected for pallet construction.

Table 1.—Mean bending properties of four grades of 2 x 4 studs from normal and beetle-killed ponderosa pine.

Stud grade	Number of tests	Fiber stress at proportional limit[2]	Modulus of rupture	Modulus of elasticity
		pounds/square inch		*pounds/square inch X 10³*
Construction[3]	30	3,705(28)	5,549(37)	1,383(20)
	33	3,952(34)	5,255(39)	1,401(18)
Standard[3]	25	3,392(38)	4,660(33)	1,352(18)
	44	3,038(42)	4,266(46)	1,256(20)
Utility[3]	39	2,334(39)	3,564(34)	1,137(22)
	45	2,596(38)	3,589(40)	1,163(18)
Economy[3]	31	1,786(46)	2,933(35)	1,039(21)
	57	2,357(32)	3,419(39)	1,054(19)
Total	304			

[1]All tests were conducted on air-dry stock at about 6.5% moisture content. Test studs were 1 1/2 inches by 3 1/2 inches; loading was on the 1 1/2-inch face, and the test span was five feet.

[2]The upper figure is for normal wood; the lower figure for wood from beetle-killed trees; numbers in parentheses are coefficients of variation, in percent.

[3]Differences between mean values for normal and beetle-killed wood by each property for each stud grade were, in all cases, not significant at the 5% level.

Figure 6.—Blue-stained paneling.

Fencing.—Appearance, as well as moderate resistance to decay, insect attack, and weathering is important for fencing. Of all the important strength properties, bending strength and nail-holding are of major importance for installation and long service life of fencing. There are few difficulties in the manufacture of fencing products from beetle-killed ponderosa pine wood. Protection against fungi and insects can be improved by simple preservative treatments. Figure 7, illustrates use of beetle-killed wood for functional decorative fencing.

Round timbers.—Beetle-killed ponderosa pine is probably best suited for applications that are not highly engineered, such as fence posts, barn poles, corral poles, and mine props. For these uses, strength properties of any member of appropriate size are usually greater than needed, and minor strength reduction in beetle-killed timber would not create a safety hazard. Round timbers from beetle-killed trees would be less suitable for utility poles and piling, where risk of failure from undetected decay or brash wood is unacceptable.

The presence of blue-stain should facilitate preservative treatment, but industry may regard this as a problem rather than a benefit because blue-stained wood tends to absorb preservative at a rate three times greater than unstained wood and tends to retain more of the preservative than is required.

Houselogs.—Houselogs are being increasingly used nationwide, but particularly in the mountain regions. Houselogs are now widely used throughout the Rocky Mountain West, including the Front Range for structures such as second homes, motels, churches,

Figure 7.—Fence posts, fence boards, and rails from beetle-killed logs.

restaurants, and year-round family residences. While ponderosa pine is not the most widely used houselog species, it helps satisfy a market for logs 7 inches in diameter and larger at the smaller end and 20 to 24 feet in length. There are no specific restrictions which preclude the use of beetle-killed trees for houselogs. The industry actually prefers sound dead trees because the moisture content is closer to in-service conditions, and fewer fabricating and use problems are encountered. For satisfactory performance, houselogs need to be dry when they are cut and fitted, and abnormal wood and irregular grain should be minimized to avoid problems in cutting logs. Consequently, relatively sound logs are required as a raw material.

Firewood.—There has been increased demand for wood for use in home fireplaces and wood-burning stoves. Dead ponderosa pine is well-suited for firewood because of its low moisture content, which makes it ready for marketing and use with less drying time. Its high resin content, which makes it ignite and burn more readily than less resinous woods is another plus.

Potential New Products

Composite panel products.—Ponderosa pine wood and fiber is particularly well-suited for composite panel products (Barger and Fleischer 1964, Markstrom, Lehman, and McNatt 1976). Particleboard utilizing ponderosa pine is manufactured in several locations in the western United States. Particleboard made from this species is preferred for several uses, such as furniture cores.

Maloney et al. (1976) revealed that dead trees of white pine and lodgepole pine could be used effectively for various types of composition board, including particleboards with only minor changes needed to optimize commercial board formulations. Lehmann and Geimer (1974), working with Douglas-fir forest residues for structural particleboard, found that only when badly decayed wood was added to the raw material was the quality of the particleboard seriously affected.

To examine the suitability of beetle-killed ponderosa pine for particleboard, six particleboard panels were manufactured and tested. The objective was to assess the effect of the dead wood on bonding characteristics using typical particleboard adhesives. Wood particles were prepared in a laboratory flaker from both live and dead trees. A screen analysis was then made to compare the differences between the wood from beetle-killed and live trees. It was found that the proportion of small particles increased slightly with beetle-killed wood dead 4 years (table 2). This is due to to changes in physical, mechanical and chemical properties that take place following beetle attack. Figure 8 illustrates the chip gradation documented in table 2. The row at the top is the screenings of the beetle-killed wood and the light colored chips at the bottom are those made from green wood.

In making the particleboard shown in figure 9, the furnish used was screened for particle sizes between 5 and 20 mesh.

The appearance of the boards was good. Panels made from beetle-killed ponderosa pine had a slightly blue color, but in all other respects were similar to panels made from live timber. The boards were evaluated by determining the density, modulus of rupture (MOR), internal bond (IB), thickness swelling (TS), and water absorption (WA). Procedures followed American Society for Testing and Materials (1980a), except for the water absorption test where a sample size of 3 x 3 inches was used, and in the thickness swelling test, only the thickness at the center point of the sample face was measured before and after the water soaking.

The results are tabulated in table 3. It should be noted that the mean MOR was above 1,600 psi, which is the requirement of Commercial Standard CS236-66 for type 1-B-1 board, but below 2,400 psi, the requirement of type 1-B-2 (U. S. Department of Commerce 1966).

Because wood used to make the particleboard was chipped under extreme conditions to assess the maximum particle fragmentation that could be expected, some substandard particleboard properties were anticipated. By selecting the 5-20 mesh portion of the furnish for making the panels, where the thickness-to-length ratio of the furnish particles was large, test

Table 2.—Screen analysis comparing the fragmentation of wood flaked from living and beetle-killed ponderosa pine trees on a weight-basis.

Screen sizes	Normal wood	Beetle-killed wood (dead for 4 years)
	Percentage of flakes on screen	
6 mesh	45.5	34.9
6 - 20 mesh	44.5	51.0
20 mesh	10.0	15.0
Average MC percent	6.3	6.0

values were lower than should ever occur in actual production. However, internal bond test values were very high and some wood failure was observed, which is a characteristic of good internal bonds. In thickness swelling and water absorbtion, the beetle-killed wood values were slightly higher (less desirable) than those of boards made from normal wood. It is reasonable to expect that the addition of wax to the binder mix would improve these properties.

These preliminary tests indicate that suitable furnish can be made from beetle-killed ponderosa pine. The effect of mixing such furnish with furnish from live trees or other available species still needs to be determined. Because there appear to be enough mill and forest residues in the Front Range to supply one or more board plants of economic size, the critical factor in composition board production may be the ability of the producer to obtain raw material at an acceptable cost.

Plywood.—Possibilities for utilizing beetle-killed wood for veneer and plywood are highly speculative. Live ponderosa pine should yield a quality of veneer that could be considered for plywood. Technical suitability depends on the physical and mechanical properties of the wood, tree size and form, knot size, and other defects that determine veneer yield and grade (Yerkes and Woodfin 1972). Surface checks and the lower and more variable moisture content of beetle-killed trees would probably result in severe veneer cutting problems. Lutz (1971) pointed out, however, that the moisture problem can be reduced by putting water back into the wood before cutting. In the particleboard tests the more permeable beetle-killed wood did not cause any appreciably detrimental effect in gluing.[2] It is, therefore, reasonable to assume no unsolvable gluing problems would develop with veneer. Because there were no major differences in pH values between

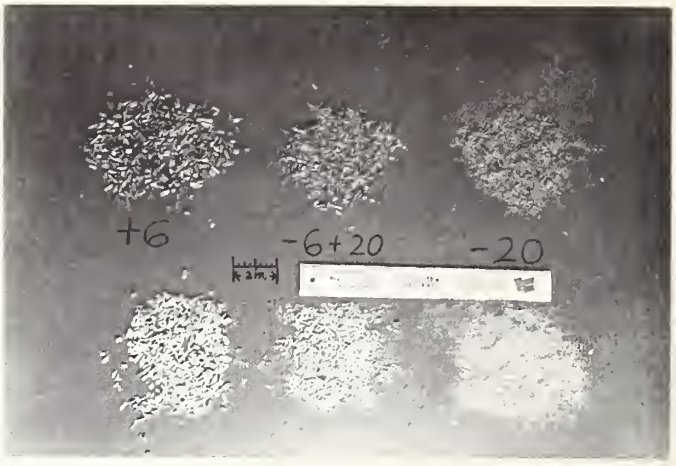

Figure 8.—Wood chips made from beetle-killed and normal green wood in the laboratory flaker.

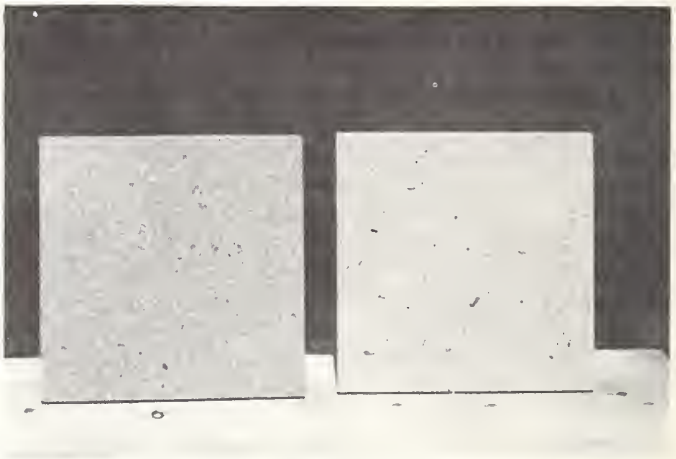

Figure 9.—Particleboard made in the CSU laboratory from beetle-killed wood and normal wood.

Table 3.—Properties of particleboard made from living and beetle-killed ponderosa pine wood.

	Normal green wood		Beetle-killed wood	
	Average	Coefficient of Variation (%)	Average	Coefficient of Variation (%)
Density (#/ft³)	48	4	46	4
MOR (Psi)	2,338	10	2,145	15
IB (Psi)	192	23	178	11
Thickness swelling (TS) (% of original thickness)	40.7	2	44.3	2
Water absorption (WA) (% of final weight)	47.3	4	41.5	3
M.C. of samples (% of oven-dried wt.)	3.94	2	4.01	1

normal and stained material, veneer from dead trees could be expected to show good glue bonding characteristics. However, the higher wettability and high absorbtion rate noted in preservative treatment indicate the potential for starved glue bonds. The degree of wood deterioration and resulting weakening in mechanical strength properties of wood associated with blue-stain could limit the suitability of the veneer and plywood made from beetle-killed wood for structural uses. However, decorative uses analogous to the blue-stained lumber paneling discussed above should be entirely feasible.

Pulp and paper.—The technical feasibility of using beetle-killed ponderosa pine wood for pulp and paper products depends on the effects of moisture content, blue-stain fungi, and deterioration by decay on the quality and yield of pulp and on the consumption of chemicals. Information on the combined effects of these factors is scarce. Levi and Dietrich (1976) claimed that chemical requirements increase with the percentage of blue-stained wood involved and the degree of pulp whiteness desired. The pulp yield and strength from blue-stain fungi infested wood is not known. However, decay in the wood would seriously reduce both yield and quality of the pulp.

As reported earlier, solubility tests with 1% sodium hydroxide revealed a substantial cell wall weight loss in wood killed by beetles 4 years earlier. From this, it might be assumed that beetle-killed wood is less attractive for pulping than normal wood, but further study would be needed to verify these limited results. However, blue stain alone should not prevent use of this raw material for pulp and paper. A 95% blue-stained sulfate pulp required only 2.5% to 5% more standard bleaching agent than unstained pulp (Levi and Dietrich 1976). This slightly higher chemical usage affects the economics of production, but does not negate the possibility that pulp of good quality and strength can be produced from blue-stained wood.

The high captial cost of a mill, large water requirements, and pollution hazards all discourage conventional chemical pulping installations in the Rocky Mountains. The Front Range situation probably would require a pulping method which has low water requirements, minimal pollution hazards, and a smaller capital investment.

Laminated wood.—Ponderosa pine, including beetle-killed wood might be used for laminated wood products. The prime advantage of laminated wood lies in its potential for upgrading product performance and values.

Through lamination, wood characteristics can be modified by selectively placing laminae of the greatest strength in sections of a member where highest stresses will occur. These increased strength properties combined with the possibility of making large-sized laminated wood products from small diameter trees offer major product advantages. Beetle-killed wood should be suitable for many laminated wood products, if by careful selection weaker material could be placed in noncritical parts of laminated members. Recent studies at Colorado State University with lodgepole pine (King 1977 and Tichy 1975) suggest that laminated dimension lumber is a product that could be potentially considered for beetle-killed ponderosa pine. Since practically all large dimension framing lumber consumed in Colorado comes from outside the region, there may be an economic advantage in local production of laminated lumber 2-inch x 10-inch x 16-foot; 2-inch x 12-inch x 16-foot; and 3-inch x 8-inch x 16-foot, nominal joist sizes.

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Front Range beetle-killed ponderosa pine wood is suitable for most traditional uses of the species. Differences are: the beetle-killed timber is drier, usually blue-stained, and may contain wood borers and decay. Mechanical properties may be affected.

Keywords: *Pinus ponderosa*, *Dendroctonus ponderosae*, forest products

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